Applied Cryptanalysis of Cryptosystems and Computer Attacks Through Hidden Ciphertexts Computer Viruses

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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

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N° 4359

Janvier 2002

THÈME 2

ISSN 0249-6399 ISRN INRIA/RR--4359--FR+ENG

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ROCQUENCOURT

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Thème 2 — Génie logiciel
et calcul symbolique
Projet Codes

Rapport de recherche n° 4359 — Janvier 2002 — 15 pages

Abstract: This report describes a class of techniques which allow either the attack of a computer or to catch the key of a cryptosystem by using a pair of (or combined) viruses, one of them being hidden in ciphertext. These techniques are valid for any operating system and can be efficiently implemented in any programming language. In order to avoid detection, the viral infection is very limited and uses polymorphic techniques. Moreover the main virus erases itself after the payload action. The general structure of the two viruses is presented and the methods of protection against such attacks is finally envisaged.

Key-words: computer security, applied cryptanalysis, block cipher, ciphertext, computer viruses, steganography, PGP, AES.

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Cryptanalyse appliquée de systèmes de chiffrement par virus

Résumé : Ce rapport présente une famille de techniques permettant d'attaquer un ordinateur ou de capturer les clefs d'un système de chiffrement en utilisant une paire de virus informatiques (encore appelés virus binaires ou combinés), l'un d'entre eux étant dissimulé dans un cryptogramme. Ces techniques sont efficaces pour tous les systèmes d'exploitation et tous les langages de programmation. Afin d'éviter la détection, l'inection est limitée et utilise des techniques polymorphes. De plus le virus principal se désinfecte lui-même après le déclenchement de sa charge finale. La structure générale des deux virus est présentée et les méthodes de protection possibles sont envisagées.

Mots-clés : sécurité informatique, cryptanalse appliquée, chiffrement symétrique, cryptogramme, virus informatiques, stéganographie, PGP, AES.

1 Introduction

The recent evolution of modern symmetric cryptology has led to the widespread use of highly secure secret key cryptosystems. Among many examples (IDEA [12], GOST [8], Blowfish [18],...) the best ones are without doubt the different candidates proposed for the A.E.S [1], for the NESSIE project [16] or at CRYPTREC [5]. The same problem is countered with highly secure steganography products (Outguess [17] and others [21]).

Despite frequent highly unrealistic claim of cryptanalysis, these cryptosystems may be considered as unbreakable for a very long time to come. Neither the brute force attack (exhaustive search on the key-space) nor the published mathematical or algorithmic analysis are likely to yield "operational, real-time" cryptanalysis for these ciphers in the next few years.

An FBI spokesman recently [4] acknowledged the fact that "*encryption can pose potentially unsurmountable challenges to law enforcement...*".

The situation is quite different when considering another kind of cryptanalysis that the "operational men" call "applied cryptanalysis".

Definition 1 *Applied cryptanalysis describes the set of all non mathematical means and techniques which aim at attacking a cryptosystem either in its implementation or its everyday use in order to endanger its secret key thus allowing easy deciphering to the attacker.*

With regards to this definition, physical techniques such as timing attack [10] and power analysis [3, 11] are recent known examples. However these techniques nearly always require highly technical knowledge, costly hardware and the need to have physical access to the cryptosystem or at least to its implementation (*e.g.* smart card).

Human compromise of the secret key user or secret key theft are less well known but have been shown to be very effective during previous wars as spying history teaches us [9]. The main drawback of this approach comes from the fact that it is both risky and incautious. Moreover, close contact with the user is always directly or indirectly necessary.

A more interesting, operational approach consists of using "infecting softwares". One of the first known attempt is the Caligula virus [20] but it was totally inefficient, since this macro virus stole encrypted, thus useless, secret key of PGP. Recently [4] the FBI has acknowledged the use of *Magic Lantern* Technology in a broader project called "*Cyber Knight*". The aim is to capture the user's secret keys by installing Trojan-like powerful software over the Internet which will perform eavesdropping of the target computer keyboard buffer. Such an approach has been very recently oberved with the new worm BadTrans [20] which essentially steals passwords by keyboard buffer eavesdropping too. Unfortunately for the attacker, due to their high replicating power, worms are bound to be detected very quickly.

The aim of this paper is to present a new technique of applied cryptanalysis using other less-known infecting malwares: binary (combined) computer viruses. In particular, we present an operational approach which effectively allowed us to remotely get the secret key of a target user, during the various experiments we conducted, without detection by

recent anti-virus softwares. In our experiments we considered several now very famous "unbreakable" cryptosystems. Each time we managed to get the user's secret key very easily. The main trick was to use the ciphertext as a "vehicle" for our attack (but other variants are now being implemented: e-mail attachement, sniffer module,...).

Combined viruses have been used in this attack (*i.e.* two computer viruses which combine their respective payload to obtain a given final effect). For details on these little known computer viruses see [7]). One resident, polymorphic, stealth virus detects the presence of a second virus, hidden by the attacker in the ciphertext, and launches it. This latter then conducts the attack itself by selectively infecting cryptosystems executables and allowing the final secret keys to escape. Just after its payload action the second virus will disinfect itself, leaving no trail of its presence. Moreover it attributes polymorphic and stealth properties to the first virus.

Thus physical access to the host computer in no longer necessary. The attack is very easy to conduct and required very limited means. Moreover it has been completely stealthy in order to avoid detection. Otherwise it would inevitably induce the user to change their secret keys.

The paper is organised as follows. Section 2 presents the general overview of these attacks. In particuliar we define precisely the operational context. In Section 3 the first infection level is presented while Section 4 describes the second level of infection. Section 5 details the different possible attacks themselves which essentially aims at attacking the cryptosystem and at "key release". The case of a simple computer attack with a trojan horse is presented as well. In Section 6 we try to envisage possible protection against these attacks.

WARNING AND CLAIM : the purpose of this paper is purely research and is not in any way to promote, help or encourage such attacks or the use of viruses. Our motivation is to draw the attention of security specialists to new attacks which have been proved dramatically efficient. We emphasise the fact that such attacks, as well as use of computer viruses, are harshly punished by the law in most of countries.

2 General Overview of the attack

We now present the general description of this family of attacks before entering into details in Sections 3, 4 and 5 and then the operational condition of our experiments.

We will not recall the definition of a virus and basic concepts on viruses that are used in this paper. Readers keen to know more will easily find out more in all common handbooks dealing with computer viruses and particularly in [7, 13].

2.1 Description of the attack

Let us consider the following setting for our attack. Two users, Alice and Bob, communicate via encrypted files. To do so they both use a strong symmetric cryptosystem denoted **S**.

Alice first encrypts her plaintext **P** with secret key **K**, producing ciphertext **C** which is finally sent to Bob.

The attacker Charlie intercepts **C** and just appends a virus executable file V_2 which will perform the attack on Bob's computer. Finally $(\mathbf{C}||\sigma||V_2)$[1] is sent to Bob after insertion of a signature σ.

Thus at a preliminary stage, Bob's computer has been infected by another virus V_1 which is of a resident, polymorphic, stealth kind. It is designed in such a way that each time Bob switches his computer on, virus V_1 is launched and stays resident. Its role is to permanently look for a received file with V_2 appended to it. When found and identified through signature σ, V_2 is launched by V_1, and ciphertext integrity is restored, that is to say V_2 and signature σ are removed from the ciphertext.

When launched V_2 looks for cryptosystem executables **S** to infect and then do so. As a consequence V_2 is a very low-infecting, victim-specific virus (generally one executable depending on to the victim's computer). When deciphering the ciphertext Bob in fact first launches virus V_2 which performs the following tasks:

1. Management of V_1 for polymorphic purposes.
2. Capture of Bob's secret key **K** used for deciphering the received ciphertext. V_2 stores it.
3. Finally returns control to the cryptosystem executable **S** which lastly deciphers the received ciphertext.

If Bob performs other decipherings before enciphering, V_2 in the same way will capture the key and store it with the previous ones if different from them. Let us suppose that secret keys $\mathbf{K}, \mathbf{K}'$ have been previously stored by V_2. When Bob performs a first enciphering (that is to say first enciphering after infection by V_2) with secret key $\mathbf{K}''$, V_2 once again is first launched and performs the following tasks :

1. Loading of the previously stored secret keys.
2. Comparison of $\mathbf{K}''$ with previously stored secret keys. If different $\mathbf{K}''$ is kept otherwise discarded. Let us suppose that V_2 has captured three different keys $\mathbf{K}, \mathbf{K}', \mathbf{K}''$.
3. Gives temporary control to **S** to produce ciphertext **C'**.
4. Takes again control and conceals secret keys $\mathbf{K}, \mathbf{K}', \mathbf{K}''$ in ciphertext **C'**[2].
5. Disinfects **S** from V_2 (on the hard disk).
6. Finally returns control to **S**.

[1] Symbol || denotes text or string concatenation

[2] In case of embedded function in **S** aiming at digitally signing **C'**, this concealment step must act before signature. An intelligence stage will provide necessary information on the software that Bob uses

The file $(\mathbf{C}', \mathbf{K}, \mathbf{K}', \mathbf{K}'')$ is sent by Bob. Charlie again intercepts this file and get the concealed keys $\mathbf{K}, \mathbf{K}', \mathbf{K}''$. The attack is completed.

Remark.- Since V_1 is still present and remains undetected the attack can be conducted as often as required by the attacker.

2.2 Experimental Settings

Different variants of this attack scenario have been conducted with several, different contexts, the context being defined as a set of the following elements:

- Different platforms. We worked essentially on Intel-based or Intel compatible platforms. Current implementation now focuses on Alpha-based platforms.
- Different operating systems (OS). Both Unix (Linux) and Windows environments have been considered. Assembly language has been used in preference for the experiments but attacks with source viruses are now under current implementation.
- Different, recent antivirus softwares (AV) in general use. We will not disclose the product's name for the following reasons: by nature AV products are unlikeky to be able to detect new viruses, especially those with new polymorphic capabilities and techniques[3].

  Our aim is not to tarnish commercial products which are nonetheless rather good and useful products against known viruses. The interest and the force of our attack is to use very specific, low-infecting viruses which use completely new polymorphic techniques. None of the AV products we tested has been efficient at detecting viruses V_1 and V_2. This unfortunately comes from a "natural" limitation in current state-of-the-art AV technology.
- Different cryptosystems have been attacked either as plain executable files or in embedded products: PGP, AES and Triple DES. Once again these attacks do not challenge intrinsic mathematical security. We considered applied cryptanalysis, not cryptanalysis. Current experiments are now dealing with steganography products where ciphertexts are replaced by images or MP3 files.

[3]Contrary to recent AV claims, detection of unknown viruses using unknown polymorphic and stealth techniques can be compared to the philosopher's stone. The best argument, among others, is that all these products are maintaining a viral signatures upgrade file. Moreover, analysis of possibly infected files in order to forecast "viral nature" is by essence condemned either to false alarm detection or to limit to already known techniques. The heuristics approach, whatever may be its true nature, can only react against unknown viruses using known techniques (stealthiness, polymorphism,....) that malware programmers borrow without improving them. See also Section 6.

3 The first infection level

Virus V_1 is designed to be a very small virus (a few hundred bits to a few kilobytes) whose polymorphic and stealth capabilities are managed by virus V_2 as described in Section 4. Its characteristics, structure and functions here follow:

1. Virus V_1 is low-infecting. It only infects computers where given target cryptosystem (or steganographic) softwares are present. A **search()** routine performs this task. According to the target computer operating system, optimal search ensures quick localisation of target executable file (scanning of the registry base, of the filesystem description table,...).

2. Virus V_1 is a resident virus. In other words immediately after first infection and each time the computer is switched on, V_1 payload is active in memory. Thus it primarily infects (OS dependant) executable files which are naturally resident, or called up during the boot sequence or are very likely to be launched by the user.

   For that, V_1 has an **isinfected()** routine to check that the host computer is not already infected and an **infect()** routine looks for specific files and infects them. Finally a **tsr()** routine makes it resident and introduces (limited) stealth capabilities.

3. The last module of V_1 to be considered is its payload. While resident, it looks for received files in order to detect signature σ. When found, **launch()** routine launches virus V_2 and restores ciphertext integrity (erasure of σ and V_2 executable code).

Figure 1 summarises V_1 structure.

4 The second infection level

Virus V_2 benefits from V_1 action. Thus whilst this latter is a very small in size, V_2 is larger and exhibits more complex functionalities and structure. Here precisely lies the interest and power of combined viruses. In turn, V_2 complements V_1 action by ensuring the complex stealth and polymorphic nature to V_1. This is done essentially by turning V_1 into a dormant state during V_2's life in Bob's computer and modifying its code before waking it up.

We developed two main variants of virus V_2. The first one aims to attack only one target cryptosystem. The second is able to treat several target cipher systems in a row. Without loss of generality here is a presentation of the first variant.

1. Virus V_2 first looks for specific cryptosystem binaries that we wish to attack. A **search()** routine performs this task. It has been optimised vis-à-vis the target computer OS, in order to optimally limit the search (reading of the FAT or equivalent filesystem structure). Another possibility is to pinpoint the exact location of target cryptosystem executable file by consulting values stored by V_1 in a previous step. This suppresses the risk of being detected by the AV computer activity monitoring. Thereafter infection is performed by a **v2infect()** routine.

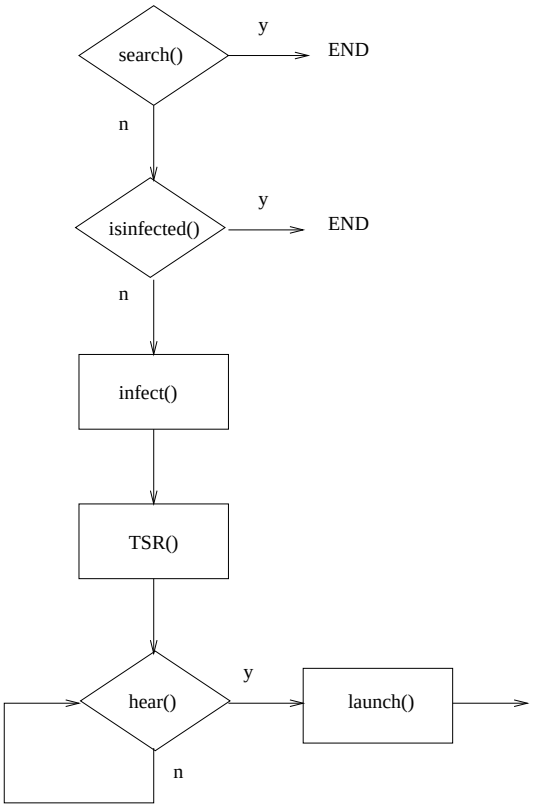

Figure 1: Virus V_1 organization chart

2. Once infection is completed, V_2 kills V_1 and disinfects the hard disk with a **v1disinfect()** routine.

3. V_2 then waits for the applied cryptanalysis itself. We describe this in Section 5.2.

4. Once V_2 has collected all the secret keys and has released them routine **v1infect()** reinfects the host computer with a modified (polymorphic) variant of V_1 (in the same way as if it were V_1 itself[4]). In particular the signature σ is changed to σ' for new potential attack.

5. Finally, last, routine **v2disinfect()** clean the target computer and remove virus V_2. The attack is completed and new conditions are set up in order to carry out this attack again.

The action of virus V_2 allows powerful polymorphism of V_1 and V_2 itself. Once again only binary viruses are able to perform this to such a high level. Figure 2 summarises V_2 structure.

5 The Payload Action

5.1 Computer Attack

We will not concentrates too much on computer attack since we primarily are interested in applied cryptanalysis. However, attacks with binary viruses in a purely computer security problem are fully and easily adaptable. We performed experiments where virus V_2 was a home-made Trojan horse (for LAN or Wan attack context). Ultimately in each experiment, we took complete control of the target computer, surrendering it up to the attacker without being detected by current antivirus softwares.

Note that in this case, it may be not possible to attach virus V_2 to a ciphertext (since the target computer owner may not use encryption at all). Thus it may be necessary to attach the virus to another kind of file. Fortunately this does not change the efficiency of the attack (see Section 6 for the other solutions).

5.2 Applied Cryptanalysis of a Cryptosystem

Whilsr remaining general overall, we shall now focus on the version we developed for when only one cryptosystem is present in the target computer. In the case of several cryptosystems attacked in a row, action and disinfection of V_2 occur according to the attacker's aim. Thus, the structure is just more complex but essentially the same.

1. On the first round of deciphering (after V_2 infection process), routine **getkey_d()** catches the user's secret key and stores it somewhere on the hard disk (location is

[4]Thus V_1 is again a resident and stealth virus but has a very different code

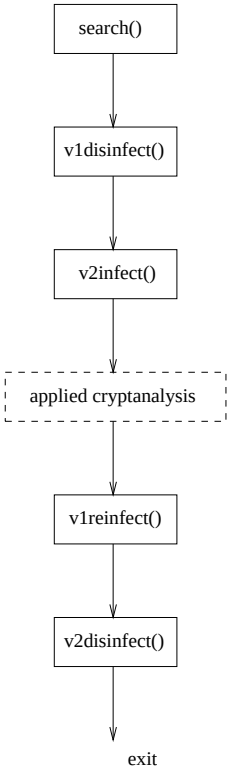

Figure 2: Virus V_2 organization chart (infection part)

different from attack to attack; **getkey_d()** moreover includes a ciphering subroutine which encrypts the key before storage).

For this part, structure of V_2 is very specific to the nature of cryptosystem binaries **S**. Indeed it must infect it in such a way that V_2 is able to temporarily pass control to **S** during its own action and before definitively abondoning control to it.

During each next decryption process the caught key is compared to previously stored keys. When different, a counter is incremented and new key is stored in the same way. V_2 then returns control to cryptosystem executable **S**. Note that infection occurs in such a way that key catching takes place at a very low level in the cryptosystem binary code in order to always have access to the plain secret key, not an encrypted version of it. Macro viruses like Caligula [20] made the mistake of stealing the key in an encrypted form.

Suitable executable infection and low level action is a far more efficient approach than simple keyboard buffer eavesdropping such as in (in so far information is available) Magic Lantern technology. The latter can easily be bypassed by not inserting secret keys via the keyboard (other possible solutions being the use of removable disk, "key gun" connected to a physical external port such as e-keys, smart cards,...).

2. At the first encryption process (after V_2 infection process; that is to say a ciphertext is about to be sent) a **getkey_e()** routine catches the key, compares it to the previously stored ones and if different keeps it.
3. V_2 passes temporily control to **S** for ciphertext generation.
4. Finally V_2 takes control again and a **concealkey()** routine enters into action. All the other stored keys are loaded and all the caught keys are encrypted with a different algorithm from that used by **getkey_d()**. They are finally hidden in the resulting ciphertext (either by insertion or by replacing ciphertext blocks). The position of the caught keys in ciphertext is computed from their own value in order to ensure random position from attack to attack. Once again it is important to note that action of V_2 for this concealment part takes place before any digital signature of ciphertext.
5. V_2 returns definitively control to **S** after completing the action of **v1infect()** and **v2disinfect()** routines.

The attack is completed. Figure 3 summarizes this scheme. **Remark**.- Note that this attack is easily adaptable to public key cryptosystems. The crucial point is to infect the executable in such a way that V_2 can access the unencrypted secret key during the computing. Only the key escape itself can be slightly different in some way.

6 Protection Issues

When considering protection against these attacks, the game seems to be rather in the attacker's favour. As a general rule in computer security, computer protection is nearly

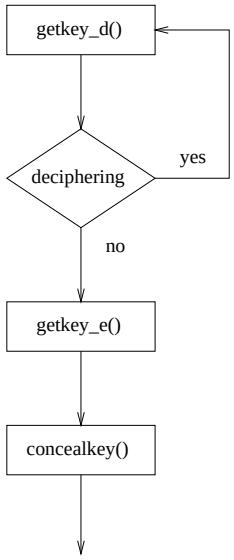

Figure 3: Virus V_2 organization chart (applied cryptanalysis part)

almost condemned to reaction, at least for the very great majority of systems. The human ability to adapt and the unbounded imagination of the attackers make such attacks generally unlikely to be forecastable and thus prevented in advance.

From the general intrusion detection (ID) point of view [14], it is clear that things are very diificult. Securing computers when dealing with the huge "number of rampant vulnerabilities in commonly used software" [14] and with the persistent lack of user's public awareness of basic computer security (even in sensitive areas like Defence) it is like trying to square the circle.

To protect against the family of attacks we presented in this paper, what are the possible different levels of action ?

- The combined use of several, antivirus softwares, preferably based more on heuristics than on scanning (in so far as heuristics may be more efficient in revealing new viruses), seems to have very weak probability for detecting new, carefully written, victim specific, **low infecting** viruses implementing new polymorphic techniques. These latter will always have great chances to remain undetected at least a long enough time to ensure several key escapings before detection. M. Ludwig [13, pp 394–396] proved that there will always be viral programs that remain undetected (for techniques limiting antivirus efficiency see also [13, Part IV] and [7, Part III]).

Our different experiments have been proven effective at fooling and bypassing all recent antiviral protection[5] we used both for V_1 and V_2. We consider that state-of-the-art antivirus programming cannot afford more than hindsight, especially against unknown polymorphic capabilities. Moreover the reverse-engineering of AVs will always yield enough useful information on how they work and how to fool them.

- The use of digital signature (for definition and details see [15, 19]) for the cryptogram, could be a solution but in fact in our case it was not. The use of combined viruses was precisely intended to bypass cryptogram signature. V_2 executable is appended to the (cryptogram || signature)-file but before signature checking, in Bob's computer virus V_1 launches V_2 and restores cryptogram integrity by deleting the element appended by the attacker. On the other hand, concealment of the captured key in the cryptogram always occurs before signature. The intended recipient will detect nothing but a few lost plaintext blocks. Such a loss may naturally occur through error transmission and may not necessarily draw the attention of the user.

- However, on the other hand, our attack, as described in this paper may be very difficult to conduct in an IPSec [6] context. However IPSec security may possibly be defeated in the future [2], at least enough to allow such viral attack. Current developments of variants of our attack seem very promising at fooling IPSec limitations. Instead of trying to concatenate virus V_2 in ciphertext, other solutions are under current testing: use of e-mail attachment, infection of non WYSIWYG document (Word documents, Postscript documents, PDF documents,...), ... The variant using e-mail attachment is very interesting, since the attack will be effective even before the file has been retrieved by the mail software in the victim computer. The fact that the mail is read or not, does not make any difference.

- This attack can be done even more passively by developing the V_1 structure and functionalities in order to render it able to "sniff" network traffic. Thus V_1 will "hear" and capture V_2 without sending it specifically to the target computer. Of course in an IPSec context, this is not possible at the present time.

Currently we still have not found any satisfactory, generic solution to this problem but research is under way to build one.

Acknowledgment

This paper is dedicated to Kim Clancy.

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http://www.inria.fr
ISSN 0249-6399